NOAA's Path to Earth System Prediction using the Unified Forecast System (UFS)

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Themes

- **Unified Forecast System updates**

- **Next-generation prediction**

- **Infrastructure challenges**

- **Organizational directions**

Unified Forecast System (UFS)

A community-based, coupled Earth modeling system, to support the Weather Enterprise and to serve as the source for NOAA's operational applications.

- **First established as part NOAA/NWS/NGGPS program in 2014**
- **Unify forecast "application" codes and infrastructure, using open, community codes**

Engagement opportunities
- **Model releases - global weather model**
- **Model analysis opportunities**
- **Annual user tutorials and workshops**

Organization
- **Steering Committee**
- **Application Teams**
- **Working Groups**

https://ufscommunity.org

Strategy Document (2021-25; Pending release) Draft Science Goals:

- Reduce near-surface biases
- Incorporate new data types targeting specific Forecast Skill Priorities
- Test and Implement a coupled component capability
- Increase physical consistency of physics and dynamics
- Establish ensemble-based methods to describe uncertainty
- Develop FV3-based Whole Atmosphere Model (for Space Weather application)

UFS Communications & Outreach
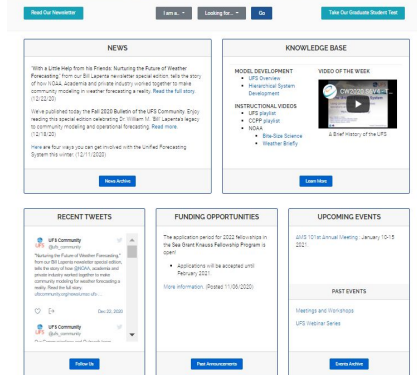
ufscommunity.org

UFS Communications & Outreach Team
- Representing broad UFS Community

UFS Community Portal (ufscommunity.org)
- Weekly updates with **24 original articles published in 2020**,
- UFS Community events, e.g. **UFS Users' Workshop in July**.

Bulletin of the UFS Community
- Publication of **3 quarterly newsletters**,
- Latest issue: **Bill Lapenta special edition**

UFS Community Survey
- First **community-wide survey** to increase participation.

Graduate Student Tests (GST)
- For code releases
- **Three GSTs completed** showing usability of UFS,
- Published new **GST for Medium-Range Weather App**,
- New GST for Short-Range Weather App available 02/2021.

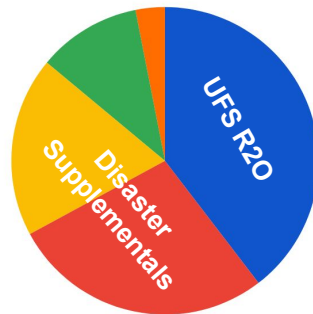UFS Bulletin, Fall 2020

NOAA Investments in UFS

Unified Forecast System (UFS)

- NOAA programs that support the UFS: NGGPS, Weeks 3&4, JTTI, pre-EPIC, and hurricane and disaster supplementals
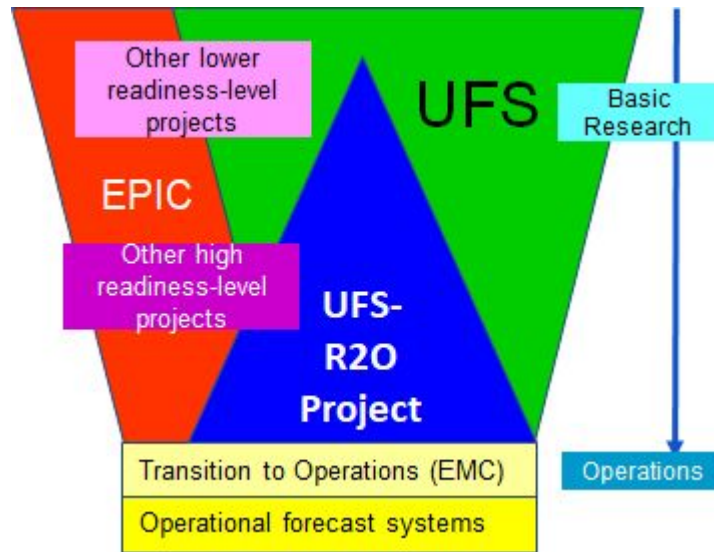
UFS Research to Operations (UFS R2O) Project

- Two year project (FY20-21) with 5-year vision
- Developing the next-generation global and regional forecast systems for NOAA's operations in FY24
- NOAA's largest investment in the UFS: $13M/yr, jointly supported by NOAA Operations (NWS) and Research (OAR)
- Community team (NOAA, NCAR, JCSDA, Universities)
- Website: https://vlab.ncep.noaa.gov/web/ufs-r2o

UFS R2O (STI & WPO) — HSUP1 — HSUP2 — pre-EPIC — JTTI

Other lower readiness-level projects

EPIC

Other high readiness-level projects

UFS

Basic Research

UFS-R2O Project

Transition to Operations (EMC)

Operational forecast systems

Operations

# UFS Application #1: Medium-Range Weather and Subseasonal-to-Seasonal (MRW/S2S)

FY24-25: Medium-Range Weather, Ensemble Subseasonal and Seasonal Forecast System *(GFSv17/GEFSv13/SFSv1)*

- **Six-way coupled Earth forecast system**
- **Weakly coupled data assimilation**
- **Reanalysis and reforecast (1982-present)**

GEFS-Aerosols   Jul-Nov 2019   MERRA2

0.01 0.05 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.2

Deliverables in FY21-22

- **Coupled model prototype runs and reanalysis-reforecast, shared with the community on AWS)**
- **Stochastic physics to account for uncertainties in atmos., ocean and land and provide probabilistic guidance**
- **Land transition from Noah to Noah-MP**
- **Data Assimilation: from GSI to JEDI**
- **JEDI-based ocean/sea ice 30yr reanalysis**
- **Atmospheric composition for S2S (aerosol-radiation, emissions, biomass burning, AOD data assimilation)**
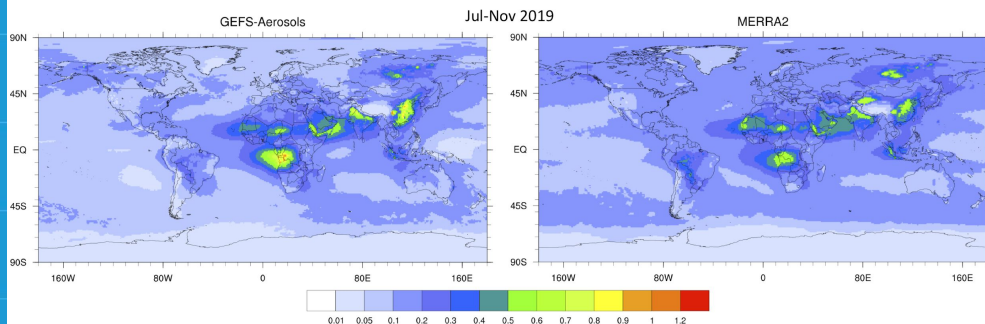
UFS MRW/S2S: Six-way Coupled Earth System

https://github.com/ufs-community/ufs-weather-model

Atmosphere
- **FV3** dynamical core
- **CCPP** physics driver
- **C768 (~13km), 127 levels**

Ocean
- **MOM6** Modular Ocean Model
- ¼ degree tripolar grid, 75 hybrid levels
- OM4 Set up [Adcroft, 2019]

Waves
- **WAVEWATCH III**
- ½ degree regular lat/lon grid
- ST4 Physics [Ardhuin, 2010]

Ice
- **CICE6** Los Alamos Sea Ice Model
- ¼ degree tripolar grid (same as ocean)

Land
- **Noah-MP**

Atmosphere Composition
- **GOCART**

Mediator
- ESMF, NUOPC, **CMEPS** mediator

UFS Application #2: Short Range Weather (SRW)

- **Rapid Refresh Forecast System (RRFS)**
  - Ensemble-based convection-allowing (~3km)
  - Unification: Replace and retire NAM+nests, RAP, HRRR, SREF, HREF
  - SRW Application 1.0 Public release - Feb. 2021
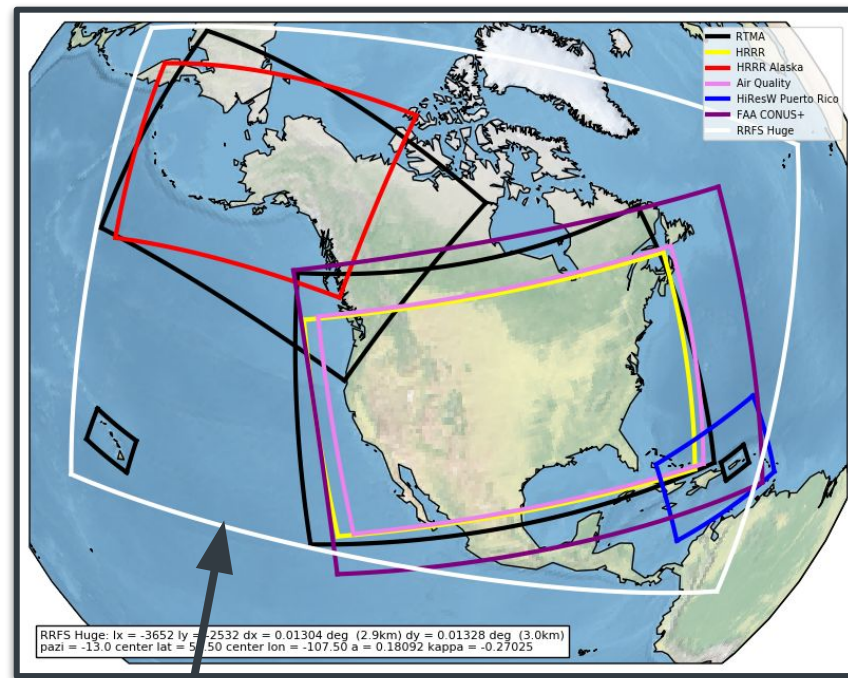 - Implementation ~2023

- **3D-RTMA/URMA (Analysis product)**
  - Implementation ~ 2023

- **Software Components**
  - Dynamic Core/Model: FV3-LAM
  - CCPP: SRW/CAM physics suite(s)
  - Data Assimilation: JEDI

- **SRW System ported to cloud!**

RRFS Huge: lx = -3652 ly = -2532 dx = 0.01304 deg (2.9km) dy = 0.01328 deg (3.0km)
pazi = -13.0 center lat = 50.50 center lon = -107.50 a = 0.18092 kappa = -0.27025

Legend: RTMA, HRRR, HRRR Alaska, Air Quality, HiResW Puerto Rico, FAA CONUS+, RRFS Huge

**3 km RRFS domain (white outline)**

UFS Application #3: Hurricane

- Hurricane Analysis and Forecast System (HAFS) to replace HWRF and HMON
  - Implementation ~2022
  - Collaboration with many partners (federal and academic)

- Future Configuration
  - Coupling with ocean (HYCOM→MOM6 and WW3)
  - Data assimilation: JEDI
  - Multiple moving nests following multiple storms

- HFIP Real-time Experiment (HREx) for HAFS, HWRF & HMON
  - HAFS IOC test in 2021

Hurricane Analysis and Forecast System (HAFS):
A collaborative Project in UFS Framework

07	NCAR/DTC	NCEP/EMC	01
06	OFCM/AOC	AOML/HRD	02
05	ESRL/NESII	GFDL	03
	04 ESRL/GSL		

FV3 Moving Nest WV at Timestep 000
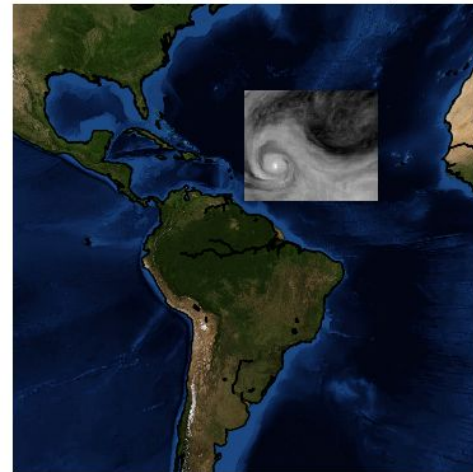
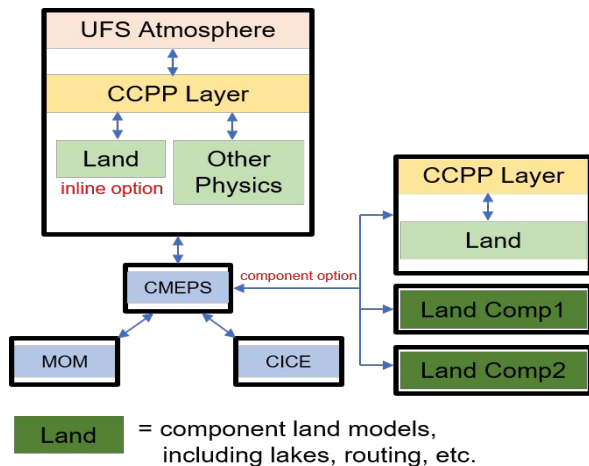# Newer UFS Applications: Land and Coastal

Land Modeling

Short-term Roadmap:
- Noah-MP updated for GFSv17

Long-term strategy
- Partnership opportunity: UFS Land model development Workshop (Spring 2021)

UFS Atmosphere → CCPP Layer → Land (inline option) / Other Physics → CMEPS → MOM / CICE

component option → CCPP Layer → Land / Land Comp1 / Land Comp2

Land = component land models, including lakes, routing, etc.

Coastal modeling

Objective:
- Forecast total water and flood inundation in the coastal zone by linking terrestrial and coastal ocean models;

Current Status:
- Operational storm surge capabilities exist in multiple NOAA line offices to meet various NOAA missions;

Example:
Maximum simulated surge (de-tided) during Superstorm Sandy (2012) near Atlantic City, NJ
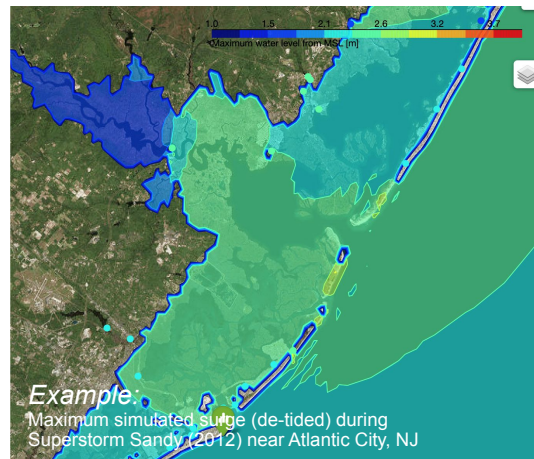
Long-term Strategy
- Long term unified strategy for coastal and terrestrial systems is needed

Cross-cutting Infrastructure

Community modeling infrastructure codes are key to
1) Unify forecast applications and
2) Entrain community innovations into operations.

Examples:

- Pre-processing
- Post-processing (UPP)
- Validation & verification (METPlus)
- Data Assimilation (JEDI) and related elements
- Physics framework (CCPP)
- Coupling (ESMF/NUOPC)
- Mediators (CMEPS)
- Common libraries
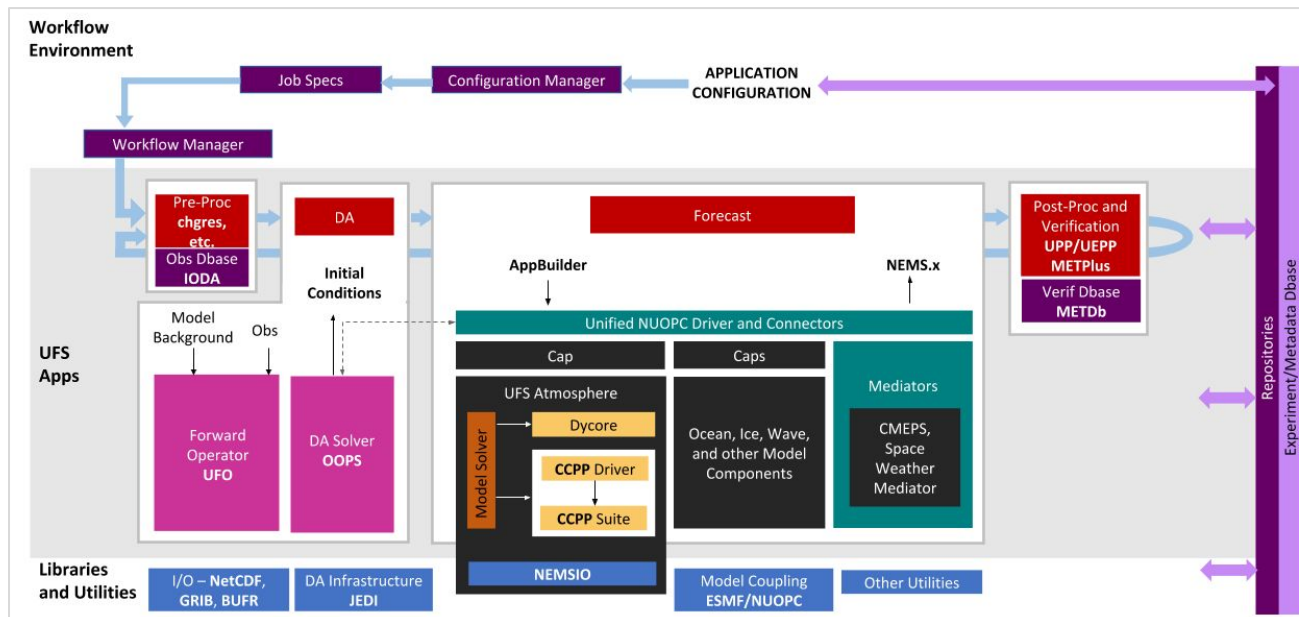
Engagement with the Field

Forecast Priorities must drive model Research and Development!

- Workshops to discern key forecaster priorities
  - "Top 20" forecast issues (Nov 2020)
  - Model-specific issues for global (Jan 2021) and regional (Feb 2021) systems
- UFS Application Teams are inviting forecaster participation

Code Retirement and Production Suite Simplification

- NOAA operations has an accumulation of legacy models and codes
- We are developing a deliberate plan and process to retire old systems.
- Transparent test-plans and continuous communication with researchers and forecasters is essential!

From Science to Computational Cost

The computational cost of the 4 major upcoming operational targets (HAFSv1, RRFSv1, RTMA-3D and GEFSv13) depends on:

1. Global coupled system → **For extended range and Earth system prediction**

2. Ensemble based → **To capture the uncertainty; and to improve initialization and forecast skill**

3. Increased spatiotemporal resolution → **To resolve the weather phenomena**

4. Increased forecast cadence and length → **To satisfy the needs of clients and society**

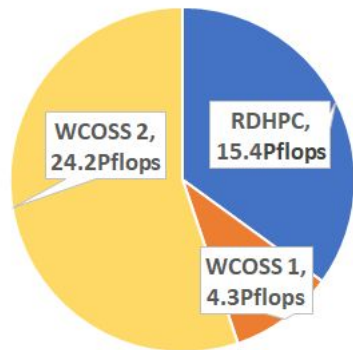**7x increase** of the computational needs **in the next 3 years** only for the UFS R2O Project activities
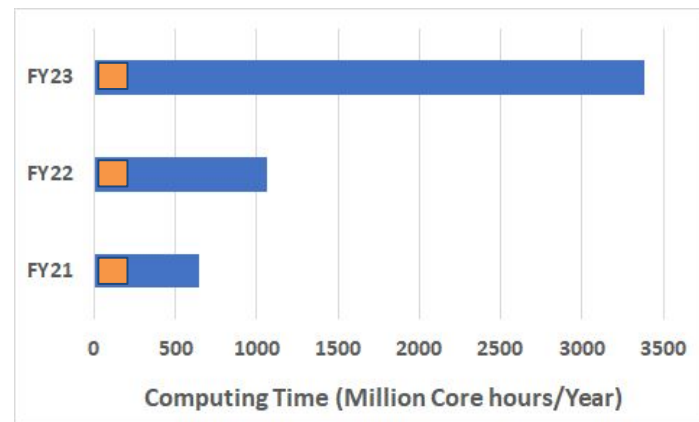
Available resources at NOAA RDHPCs

Computing Resources

The HPC Resources shortfall is the Largest Constraint to NOAA forecast improvement

Performance of NOAA HPC

Research-to-operations capacity
ideal is 6:1
Requires 9x Increase to NOAA R&D computing

Computing strategies

- Codes open on Github
- Supported releases
- Applying to non-NOAA HPC, e.g. the MRW/S2S team was granted $2.8M resources at NSF XSEDE
- Use of cloud resources:
  - Coupled simulation prototype outputs from the UFS-R2O are publicly released and some cloud resources for analysis are available
  - Reanalysis simulations available on AWS
- Explore forward-looking HPC technology, e.g., on GPUs or ARM
- Advance model software: testing, documentation, common libraries and infrastructure

Future directions and community opportunities

- **Organizational developments**
  - NOAA: formalizing cross-line office modeling coordination (Research, Operations, Ocean services, Fisheries, Satellite Observations)
  - Community: research institutions, private industry, other agency partners
  - Together these will need to "govern" the UFS, from innovation to operations
- **Earth system prediction developments**
  - Coupled Modeling (common system from climate to weather)
  - Land and ocean biogeochemistry
  - Coastal systems
- **Code releases**
  - Global operational system (MRW) available
  - Regional development system SRW (Feb 2021)
  - Coupled development system (available but not yet supported - work with developers)
- **Cloud computing**
  - Reanalysis-reforecast (GEFS v12) available on AWS
  - Coupled model prototype and cloud resource for analysis
  - Global and Regional systems running on cloud and will be made available with releases

Thank-you!

UFS-R2O Project: **https://vlab.ncep.noaa.gov/web/ufs-r2o**

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